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MATERIALS STUDIES FOR SOLAR CELL STRUCTURES

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INTRODUCTION

The purpose of this research program is the study of possible techniques for reducing the surface recombination losses in solar cell structures. The primary material to be investigated is InP. Samples of epitaxial InP were grown for subsequent chemical surface treatment. The surface investigations employed relative photoluminescence intensity (PLI) measurements. The surface emission or transmitted PLI techniques were similar to those described by Mettler [1] and Jenkins, *et al.* [2].

Another aspect of the research activities was the completion of a metal-organic vapor phase epitaxy system which could be used for some of the sample preparation and surface treatment processes.

SURFACE RECOMBINATION STUDIES IN InP

Epitaxial Layer Preparation

Approximately 5 μm thick layers of tin and zinc doped InP were grown by liquid phase electroepitaxy (LPEE) on InP substrates [1]. The surfaces of the LPEE-grown material do contain microscopic pits and striations, and thus the quality may vary over the area of the 1x1 cm substrates. The Hall measurement carrier concentrations in the 5 μm layers were in the 10^{17} - 10^{18} cm^{-3} range.

Photoluminescence Measurement System

The photoluminescence intensity of the epitaxial samples was determined at room temperature using an 2 W argon ion laser as an excitation source at 514 or 488 nm. For spectral measurements the PL emission was collected with a lens and focussed onto the entrance slit of a 0.5-meter diffraction grating spectrometer. The detection system consisted of a 270 Hz laser beam chopper, a photomultiplier and a lock-in amplifier. The

sample was mounted on a Si photovoltaic detector which could be connected to the lock-in amplifier system for detection of the integrated transmitted PLI. Laser line optical bandpass filters were used to eliminate extraneous long wavelength emission from the laser. Also coupled into the optical system was a 35 mW He-Ne laser providing a more penetrating excitation at 632 nm. A laser power controller was inserted in the He-Ne beam to stabilize the intensity at the sample, while the argon ion laser had an internal light intensity stabilizer. A feature of the optical system was the converging of the two laser beams through the chopper wheel such that the lock-in amplifier output represented the difference signal due to the two excitation wavelengths. This alignment is difficult to achieve, since the duty cycle, incident position and intensity must be matched for the two beams.

In this dual-wavelength excitation mode of PLI the argon laser intensity was adjusted at a particular spectrometer wavelength, e.g., 0.92 μm , to yield a lock-in amplifier output of zero. Then a spectral scan of the PLI was performed in an attempt to observe the difference signal representing the anticipated sensitivity of the PLI to the absorption depth of the excitation. The current results have been inconclusive with this mode of PLI measurement, but perhaps the differential measurement concept can be improved if samples can be prepared with larger variations in PLI.

The measurement of the integrated transmitted PLI measurement can also be performed with the optical system with continuous or chopped excitation. Conceivably, the sample could be spectrally scanned with the dual wavelength excitation process in the transmission method also.

Photoreflectance spectroscopy (PRS) was proposed as a possible alternative surface characterization technique in this research effort. While a PRS system was developed temporarily in the laboratory, the source of funding for that system has been discontinued until a suitable new laboratory space can be acquired and renovated.

Surface Treatments

One of the wet chemical surface treatments tried was that reported by Jenkins, *et al.* utilizing 15% HF in deionized water [2]. After soaking for 30 minutes in this solution, the transmitted PLI was observed to increase by perhaps a factor of 2 with respect to the as-grown epilayer surface. Also, as observed by Jenkins, *et al.* this PLI decayed with continued exposure to the Ar ion laser beam. Another chemical treatment used to decrease the surface recombination velocity in GaAs is the application of an aqueous $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ solution [3,4]. The sulfide was prepared here in a 1.0 M concentration, dropped on the InP surface and spun at 5000 RPM to create a thin layer as the solution dried. Visually, this film was very nonuniform with striations, and the PLI was decreased considerably with respect to the surface before treatment. It is not known whether the PLI reduction is due to attenuation losses in the sulfide layer or to an increase in the surface recombination velocity.

Various sulfur surface treatments have been studied with respect to the inferred reduction in interface state densities on III-V semiconductors. Kapila and Malhotra [5] passivated InP surfaces with a polysulfide solution treatment followed by a SiN_x film deposition. *In situ* PLI, and capacitance-voltage (CV) measurements on $\text{Al/SiN}_x/\text{InP}$ structures were used to study the effect of the treatments. Ashby, *et al.* [6] used

ultraviolet (UV) light to promote a reaction between elemental sulfur vapor and a GaAs surface. The resulting PLI enhancement degraded quickly with exposure to the atmosphere. Tabib-Azar, *et al.* [7] deposited insulating cubic GaS on GaAs by chemical vapor deposition. Again, PLI and CV measurements were performed with increases in PLI of over 100 times and accumulation/inversion behavior in the CV response. Thus, the treatment of GaAs and InP surfaces with a chemically reacted or deposited sulfide layer has the effect of reducing the apparent surface recombination velocity, either by reducing the surface/interface state density or altering the energy band bending at the surface. In the future work we are planning to investigate some combinations of the above processes for use with GaAs and InP.

METALORGANIC VAPOR PHASE EPITAXY SYSTEM

A vertical metalorganic vapor phase epitaxy (MOVPE) system has been installed with capability for growing III-V epilayers at atmospheric pressure. Operation of this system has been repeatedly delayed by various building and laboratory area renovations/repairs. The arsine (10% AsH₃ in H₂) inlet line has been fitted with a molecular sieve drying filter. A Novapure [8] exhaust treatment system has been installed to replace the original cracking furnace. The cracking furnace utilized a rather fragile quartz furnace tube and an explosion in the reactor chamber was attributed to insufficient purging of the furnace system before heating and initiating the hydrogen carrier gas flow.

PLANNED FUTURE WORK

A variation of the sulfur treatment investigated by Ashby, *et al.* [6] will be implemented using an existing remote plasma chemical vapor deposition (RPCVD)

system. We are currently studying the deposition of SiN_x films on substrates at 300 °C using silane and nitrogen as the reactant gases. The RPCVD system can be modified easily to provide an additional valved connection for an elemental sulfur source and a quartz window for UV light illumination of the substrate. UV or remote plasma excitation of the sulfur vapor will be utilized to initiate the surface reaction with vendor-supplied GaAs and InP substrates. Subsequent deposition of the SiN_x layer may permit surface stabilization for the PLI studies.

The MOVPE system will be modified by adding a liquid source channel to the Group V inlet manifold. This channel (which could also be reconnected to the Group III manifold) will be used with a tertiarybutylarsine (TBA) source. TBA is reported to have a lower decomposition temperature than arsine, and thus may be more useful for the arsenic stabilization of InP surfaces in the MOVPE reactor. InP surfaces decompose at temperatures above about 400 °C. If a portion of the TBA as arsenic can be reacted with the InP, then the resulting surface may be passivated. This approach for InP passivation was studied by Hollinger, *et al.* [9]; however, their work was performed at 10^{-5} Torr in a molecular beam epitaxy system.

REFERENCES

- [1] K. Mettler, Appl. Phys., **12**, 75 (1977).
- [2] P. Jenkins, M. Ghalla-Goradia, Mircea Faur, S. Bailey, and Maria Faur, Proceedings of the 21st IEEE Photovoltaic Specialists Conference, 399 (1990).
- [3] B. Skromme, C. Sandroff, E. Yablonovitch, and T. Gmitter, Appl. Phys. Lett., **51**, 2022 (1987).
- [4] E. Yablonovitch, C. Sandroff, R. Bhat, and T. Gmitter, Appl. Phys. Lett., **51**, 439 (1987).
- [5] A. Kapila and V. Malhotra, Appl. Phys. Lett., **62**, 1009 (1993).
- [6] C. Ashby, K. Zavadil, A. Howard, and B. Hammons, presented at the 1993 Electronics Materials Conference, Santa Barbara, CA (June 25, 1993).
- [7] M. Tabib-Azar, S. Kang, A. MacInnes, M. Power, A. Barron, P. Jenkins, and A. Hepp, Appl. Phys. Lett., **63**, 625 (1993).
- [8] Novapure Corp., Danbury, CT.
- [9] G. Hollinger, R. Blanchet, M. Gendry, C. Santinelli, R. Skheyta, and P. Viktorovitch, J. Appl. Phys., **67**, 4173 (1990).